CHAPTER 4

STUDY ON THE ACOUSTIC PROPERTIES OF JACK FRUIT WOOD AND COMPOSITE MATERIAL

4.1 INTRODUCTION

The development of fibre reinforced composite structure presents an ideal opportunity to enhance the use of composite materials for musical instruments. As discussed in Chapter 2, composite materials have a high potential to act as an alternative material. However, before applying these composites into mass production, their acoustics characteristics have to be studied. Determination of the elastic modulus and the damping factor should be analysed in detail and is of critical importance. This chapter highlights the experimental investigations into partial characterisation of the acoustic properties of jackfruit wood and sandwich composite.

4.2 PREPARATION OF WOOD SPECIMENS

The jackfruit wood was collected from a local drum shell manufacturer (Sree Shankara Wood Works) from Kalady, Kerala. All the wood samples were collected from the same wooden log. The selection was based on visual inspection of logs. Quarter sawn (Figure 4.1) wood specimens (J1) were cut to dimensions of 160x12x2 mm (Length x width x thickness). Quarter sawing is superior compared to flat sawing specimens due to its unique orthotropic property in three primary orthogonal directions. Specimens were cut using a circular saw with a quality finishing blade and specific
machining guide and fixture. This procedure ensures smooth surface finish. The total number of specimens was 27. Sufficient care was taken to prepare the specimens. In the laboratory, wood specimens were conditioned for 8 weeks in standard air-dry regulated conditions (20±1 °C and 60-65% relative humidity). Figure 4.2 shows the actual wood specimen.

Figure 4.1 Schematic indicating the location of the specimen cut from the log

Figure 4.2 Actual wood specimen
4.3 PREPARATION OF COMPOSITE SPECIMENS

In order to fabricate the samples the following materials are procured. Balsa wood core (155 g/cc), 2 mm thick were supplied by M/s DIAB, Montreal. The epoxy resin (Sikadur 300) was supplied from Sika Corporation, USA. Unidirectional carbon fibres (350 GSM) were obtained from McGill University in Montreal. Carbon fibre sandwich flat plates were prepared by the vacuum bagging technique (Figure 4.3). From the large plate, specimens were cut into 160x 12x 3 mm (Length x width x thickness) using a circular saw with quality finishing blade. A detailed description of vacuum bagging process is given in chapter 5.

![Figure 4.3 Preparation of composite samples](image)

During the sample preparation the alignment of the carbon fibres was carefully chosen to study acoustic parameters in different directions of reinforcement. The unidirectional carbon fibres (face sheet) were oriented perpendicular to the flat swan balsa wood (S1) and parallel to the long grain direction of the balsa wood (S2) illustrated in Figure 4.4. Further, the results are compared with that of randomly oriented natural fibre flax composite (NF1). To summarise, the parameters to evaluate the wood and composites were density, dynamic Young’s modulus and damping factor. The labelling of the samples is given in the following Table 4.1.
Figure 4.4 (a) Schematic of Sample S1; (b) Schematic of Sample S2; (c) Schematic of natural flax fibre composite (NF1)
Table 4.1 Description of samples

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Samples Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jackfruit wood</td>
<td>J1</td>
</tr>
<tr>
<td>2</td>
<td>Unidirectional Carbon fibre/balsa sandwich. (Reinforcement perpendicular to the direction of the fibre)</td>
<td>S1</td>
</tr>
<tr>
<td>3</td>
<td>Unidirectional Carbon fibre/balsa sandwich. (Reinforcement along the direction of the fibre)</td>
<td>S2</td>
</tr>
<tr>
<td>4</td>
<td>Randomly oriented flax fibre epoxy composite</td>
<td>NF1</td>
</tr>
</tbody>
</table>

4.4 ACOUSTIC BEHAVIOUR OF WOOD AND COMPOSITES

The acoustic behaviour of wood and composite bars as prepared above was measured using the method discussed in section 3.2. The important vibrational properties of spruce wood (used for soundboards) along the grain direction is highlighted by (Obataya et al 2000). In addition to the specific dynamic modulus of elasticity ($E'/\rho$), which is desirable for basic characterisation of materials for musical instruments, other parameters known for efficiently choosing a material for musical instruments was also measured. For example, the characteristic impedance $z$ (Equation 4.1) is related to the transmission of vibration from one medium to another (Brémaud 2012; Wegst 2008)

$$z = \sqrt{(E\rho)}$$  \hspace{1cm} (4.1)

4.5 RESULTS AND DISCUSSION ON ACOUSTIC BEHAVIOUR

The results of important acoustic parameters are summarised in Table 4.2.
Table 4.2 Vibrational characteristics of wood and composites

<table>
<thead>
<tr>
<th>Description of sample</th>
<th>Direction of measurement</th>
<th>Density, $\rho$ (g/cm$^3$)</th>
<th>Dynamic Young’s Modulus (GPa)</th>
<th>Specific Dynamic Modulus $E/\rho$ (MPa m$^3$ kg$^{-1}$)</th>
<th>Damping ($10^3$) Q$^{-1}$</th>
<th>Impedance, $z$ (kg m$^{-2}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jackfruit wood (JI)</td>
<td>Axial (L)</td>
<td>0.635</td>
<td>9.86</td>
<td>15.47</td>
<td>7.59</td>
<td>2503</td>
</tr>
<tr>
<td>Balsa-carbon sandwich (S1)</td>
<td>Along carbon fibres</td>
<td>0.307</td>
<td>21.35</td>
<td>69.43</td>
<td>5.68</td>
<td>2562</td>
</tr>
<tr>
<td></td>
<td>Perpendicular to the fibres</td>
<td>0.302</td>
<td>4.11</td>
<td>13.62</td>
<td>16.92</td>
<td>113</td>
</tr>
<tr>
<td>Balsa-carbon sandwich (S2)</td>
<td>Along carbon fibres</td>
<td>0.325</td>
<td>31.5</td>
<td>96.81</td>
<td>3.5</td>
<td>3203</td>
</tr>
<tr>
<td></td>
<td>Perpendicular to the fibres</td>
<td>0.326</td>
<td>0.538</td>
<td>1.65</td>
<td>42.82</td>
<td>419</td>
</tr>
<tr>
<td>NF1</td>
<td></td>
<td>1.033</td>
<td>3.5</td>
<td>3.39</td>
<td>18.5</td>
<td>1901</td>
</tr>
</tbody>
</table>
4.5.1 Density

Due to the large difference in bulk density of the materials it was more useful to compare their specific properties. The width and thickness of the samples were measured at 3 points of the specimen and the length was measured only at one point as prescribed by ASTM standards. The density, \( \rho \) of the sample was obtained by dividing the calculated volume by the mass of the sample. The densities of the wood samples were varied from 0.673 g cm\(^{-3}\) to 0.635 g cm\(^{-3}\). Generally the density of wood is characterized by the porosity (Bremaud et al 2012). Figure 4.5 shows the comparison of densities for wood and composites.

![Figure 4.5 Density of measured materials](image)

**Figure 4.5 Density of measured materials**

Compared to the Jackfruit wood, the density of balsa/carbon fibre composites is 53% lower. However, the densities of NF1 composites are 65% higher than that of jack fruit wood. This high density of the natural fibre composite may find applications in making xylophone (percussion instrument) bars. The result suggests that sandwich construction offer a
potential weight reduction in musical instrument structural applications which is the primary motivation of this study.

4.5.2 Dynamic Young’s Modulus

The Dynamic Young’s Modulus (E’), of J1, which is an indicator of mean specific modulus, was normally distributed at 9.86 GPa. Figure 4.6 shows the comparison of dynamic Young’s modulus. Young’s modulus in the wood grain direction is also measured by static tensile testing. The variation in the Young’s modulus measured by both the static and dynamic tests (under 1 kHz) is less than 2%. This is in accordance with the results obtained to that of Philips (2009). The balsa carbon sandwich with reinforcement perpendicular (S1) to wood grain has values of Young’s modulus in the upper average range of tropical hardwoods. The higher value of Young’s modulus is due to presence of strong fibres. Due to much lower density of the core material, the specific modulus measured along the fibre direction is twice that of the maximum range of wood, (Bremaud 2012).

Further, the samples S2 measured along the fibre have much higher values of E’. In this case, specific modulus being unrealistic compared to wood values. NF1 have lower values of specific modulus compared to sandwich composite and jackfruit wood. E’ is the ratio of stress to strain under vibratory conditions which is calculated in this study from free-free vibration test. In percussion drum; shell is subjected to vibration and hence E’ is considered as a major parameter for the selection of composites. From the results obtained J1 is comparable to that of S1 measured perpendicular to fibres. In J1 the fibres are oriented along the wood grain direction and the stress distribution is similar to that of S1. However, a reduction of approximately 50% is due to the density of J1 being approximately 50% more than that of S1 measured perpendicular to that of fibres. This also confirms that there exists a direct relationship between the density and Young’s
modulus. However, dramatic different elastic modulus is due to the anisotropy of the applied materials.

![Figure 4.6 Dynamic Young's modulus of measured materials](image)

**Figure 4.6 Dynamic Young's modulus of measured materials**

### 4.5.3 Specific Dynamic Modulus

Specific Dynamic Modulus is the ratio of $E'$ to $\rho$. Figure 4.7 shows the comparison of specific dynamic modulus of wood and composites. As discussed above $E'$ is directly proportional to $\rho$, $E'/\rho$ is a constant and obviously the sample with higher value of $E'$ will have higher value of $E'/\rho$ which is in line with the obtained results. Due to the anisotropy of composite samples that were tested (along the carbon fibre direction) showed very high value of specific dynamic modulus. However, across the fibre direction the values are relatively lower than that of jack fruit wood.
4.5.4 Damping Factor

Damping factor is an indicator of the internal friction which is desired to be as less as possible for a material which could be used for making musical instruments (Mehadi et al. 2014). Damping is loss of energy in a vibratory system. The released sound from a wood specimen weakens after a while due to the damping vibration energy within the specimen. Figure 4.8 shows the comparison of damping factor for the measured materials. In the case of wood, damping property is directly proportional to the cell-wall substance. Damping factor is related to quality factor (Q) which is expressed as \((\tan \delta = 1/Q)\) is an indicator of the sound quality of the material. The jackfruit wood has shown lower damping values. The samples S1 have damping coefficient (both axial and transverse) which are close to the classical wood values reported in the literature (Bremaud et al 2012). The damping values of S2 have extreme values for wood. The results obtained for
damping reveals that on an average those with higher values of E’ have lower damping factor and vice versa. This is in accordance to the study done by Holz (1996).

![Figure 4.8 Damping of measured materials](image)

**4.5.5 Impedance**

Impedance, $z$ of a material is defined as the product materials speed of sound, $c$ and its density $\rho$. $z = cp$; where, $c = \sqrt{E/\rho}$. The characteristic impedance of a material as seen from the above results is directly related to the modulus of elasticity and density. Figure 4.9 shows the comparison of impedance. A close correlation is obtained for the wood samples and the S1 measured along the fibre direction.
Figure 4.9  Impedance of measured materials

From the above results it can be concluded that J1 matches with S1 in all compared vibrational parameters. In order to find a suitable alternative for J1 the substitute selected should have matching vibrational properties and hence S1 is the most preferred substitute from the compared samples. In order to mimic the resonance wood used in traditional instruments the mechanical and acoustic properties should be tailored to specific end-use applications. However, this comparison is more applicable for stringed instrument soundboard and xylophone structures where the sound is primarily radiated from the wood.

For Indian drum Chenda, the sound is primarily radiated from the skin rather than the shell. Hence the selection criteria are mostly characterized by the mechanical stability, ease of workability and aesthetics. The comparison of results from the vibration test shows that carbon/balsa sandwich structure with reinforcement perpendicular to the balsa wood, S1 has the mechanical and damping properties comparable to that of Jackfruit wood.
4.6 SUMMARY ON ACOUSTIC BEHAVIOUR

The vibrational properties of the wood and the proposed composites were investigated and compared. The results obtained in this study will be useful in improving the efficiency of selecting wood alternatives for musical instruments. The balsa wood sandwich structure having reinforcement perpendicular to the direction of fibres shows density, specific modulus and damping coefficient comparable to that of jackfruit wood. This also suggests that carbon/balsa sandwich composite could replace strength driven applications. Now if the composite plate/shell can be made cheaper and/or faster, it has more repeatability, and more mechanical stability (against creeping and humidity), it is practically more suitable to make musical instruments.